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Wall cladding: designing to minimise defects due to inaccuracies and movements

This digest deals with non-loadbearing cladding and facings. It is concerned mainly with the factors that influence rain penetration and dislodgement, commenting on the critical points to be considered in design, execution and supervision, so that defects of these kinds can be minimised. Readers are recommended to read also Digest 217, which deals with the diagnosis of causes of these defects and is relevant, therefore, to 'design' also. Cladding may be required to contribute to building performance in other respects, eg thermal insulation and fire; these, and considerations affecting the building as a whole, such as foundation movements, are not dealt with. The guidance provided is unavoidably in general terms and must be interpreted according to the specific circumstances of exposure, building height and construction materials.

Key issues

Inaccuracies and movements in both cladding and supporting structures affect all claddings and need to be considered in combination. Both can affect fixings, bearings and joints so as to influence weathertightness or safety. For example, when joints are small as a result of inaccuracies, movements may be large in relation to joint width so that sealants are over-strained; rain penetration may then ensue. Further movement after the joint has closed can damage fixings and dislodge cladding. Fixings, because they are between cladding and structure, are therefore between two parts of construction that will almost always move by different amounts and, commonly, in different directions.

Movements caused by changes in temperature or moisture content and by shrinkage are directly related to size. Differential movements between cladding and structure can always be expected to occur and it is particularly important to consider the sizes of those areas of cladding that will behave as an entity (if, for example, joints within an area are incompressible). Listed below are the principal factors determining the effects of movements and inaccuracies. Calculations of these effects provides basic data for use in design:

Size of any part of the cladding which will behave as an entity, and expected change in size with change of temperature and moisture content. Corresponding size of supporting structure or background*, and expected change in size with change in temperature and moisture content, and shrinkage, deflection and creep. Relative direction of movements between cladding and structure or background*: whether movements act together or in opposing directions.

Extent and direction of the movements considered above at joints, fixings, above and below bearings and at other locations such as those where there is a change of background materials or construction. Predicted inaccuracies of cladding and structure (see BS5606).

Predicted effects of inaccuracies on joints, fixings and bearings (see Digest 199).

These considerations are an important part of the basis on which to select, or design, jointing details and materials (including those for special joints such as "compression" joints), fixing details (and the separate provisions for adjustability and for movement that they will need) and bearing sizes and limits.

*The term 'background' is intended to cover the case in which cladding is attached directly, without an intervening gap, for example, tiled rendered brickwork.

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Movements

It is critically important to examine potential designs for those dimensional changes in service which will produce *relative* movements between cladding and structure or background. The principle illustrated in Fig. 1 may be a self-evident one, but the design problem is, of course, to translate it into its practical effect at particular locations and in particular circumstances. The dotted "links" in Fig. 1 illustrate how the problem becomes increasingly important with increase in the dimension over which relative movement occurs. Fig. 1, though shown as if it applied in the vertical plane, may equally apply on plan. Also, while it shows the commonest condition, of cladding moving "positively" with respect to the structure, the reverse may also occur, though generally with less damage. The implications of Fig. 1 in practice are made apparent by visualising, imposed upon it, design arrangements for fixings, for eaves overhang, for projecting floors or columns, for compressible or incompressible cladding joints, for adhesion between cladding and background and so on.

The relative movements illustrated by Fig. 1 may be reversible (for example, seasonally, daily, or even over periods of a few minutes) or irreversible (for example, shrinkage of cement-based materials, creep under sustained load, moisture expansion of brickwork). Movements with different causes (also reversible and irreversible) may operate simultaneously and may be characteristic of either cladding or structure or both. And, as noted earlier, the problem cannot be considered in isolation from the effects of inaccuracies. However, if each contributory factor is examined in turn and allocated a value, or discounted if appropriate, their combined effect at critical points can be assessed.

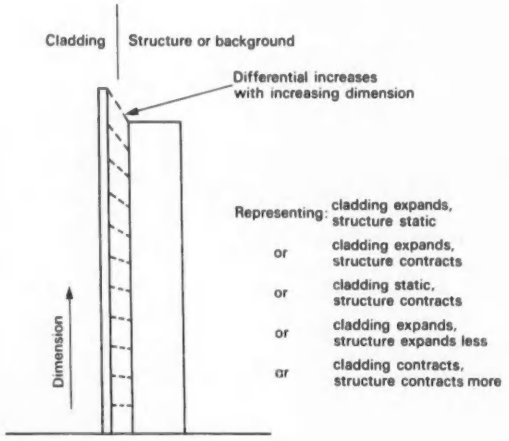

Fig 1 "... the problem becomes increasingly important with increase in dimension over which the relative movement occurs"

Table 1 lists the kinds of movements that occur. It thus first provides assistance in the choice of materials. Subsequently, more detailed consideration can be given, quantifying the expected movements and thus the amounts and directions of relative movements. The effects of constraints provided by fixings, bearings or containment by other parts, in concentrating relative movements at particular locations, can be evaluated and the implications for the design of joints and fixings can then be examined.

Inaccuracies and movements at joints

So far as movements alone are concerned, joints fall into two main categories: rigid joints that permit no movement (for example, welded, glued or bolted joints) and flexible joints which permit both expansion and contraction (for example, open joints, sealant-filled or gasketted joints). The mortar joint is something of a hybrid of both categories but in this context its predominant feature is its incompressibility.

The importance of rigid joints here is that they produce an assembly, larger than its jointed parts, that will behave as an entity, and so accentuate the problem illustrated in principle in Fig. 1. The importance of joints in the second category is that the limitations imposed by the capabilities of jointing materials (sealants, gaskets, baffles etc.) need to be carefully compared with the effects, at the joint, of movements and inaccuracies. Also in this category are those joints at which substantial relative movement must be accommodated and which, although called "expansion joints", "compression joints", always need in practice to be able to accommodate movement of both kinds. Flexible joints cannot safely be designed on the assumption of a particular single value of intended width. A single width value, such as is commonly specified, cannot be achieved consistently (because of unavoidable inaccuracies) and a joint that chances initially to have the specified width will not remain at that width (because of movements in service). The important characteristic of such a joint, whatever its detail design, is that it has in-built limits of width within which it can perform satisfactorily. The working limits of size can be identified by inspection of the design details—for example, comparing the width of a baffle with the depths of the grooves, or determining the least and greatest compression appropriate to a gasket. The limits so identified may be modified by other factors such as the need for installation clearance. There is little point in determining the limits very precisely provided that one errs in the safe direction. These limits then provide criteria for comparison with the predicted effects of movements and inaccuracies on joint widths, so that the designer can select or design an appropriate joint. Subsequently, the limits can be specified to the builder so that he can know whether or not constructed joints are satisfactory in this critically important respect. He has no means of judging satisfactoriness if, for example, "12 mm joints" are specified. Exactly similar considerations

Table 1—Movements that may affect cladding

Cause	Effect	Duration, frequency	Examples of materials or components affected	Significance for design
1 Temperature changes	Expansion and contraction	Intermittent, diurnal, seasonal	All. Where restrained, distortion or damage may occur. Distortion may also result from temperature gradients or from from non-homogeneity	Extent of movement is influenced by thermal coefficient, exposure, colour, thermal capacity, insulation provided by backing
2 Moisture content changes:				
a) Initial moisture absorption	Irreversible expansion	Relatively short term, due to absorbtion of moisture after manufacture	Brick and other ceramic products	Depends on age of product most movement occurs within first 3 months of product's life
b) Initial moisture release	Irreversible contraction	Relatively short term	Mortar, concrete, sand-lime bricks	May require measures to control or distribute cracking
c) Alternate absorption release of moisture in service	Expansion and contraction	Periodic—e.g. seasonal	Most porous building materials, including cement based and wood or wood based products. Restraints, humidity gradients or non-homogeneity may produce distortion. Laminates of dissimilar materials may bow particularly if their construction is asymmetrical	Generally less significant for cladding than are thermal movements but wood experiences large moisture induced movements across the grain.
3 Loading on structure:				
a) Elastic deformation under service loads	Normally insignificant in vertical members but horizontal members may deflect	Continuous or intermittent under live loads; long term under dead loads	Suspended floor and roof slabs, beams, edge beams or spandrels, of all materials (whether they support or "contain" the cladding)	Needs consideration in relation to fixings and bearings for cladding and to possible compression of "contained" cladding; deflections in pre-stressed concrete members may be relatively large
Creep	Contraction of vertical and deflection of horizontal members	Long term	Reinforced and pre-stressed concrete components as above	Needs consideration as above. May also be significant where load bearing concrete walls or columns have cladding such as mosaic or other tiling directly bonded
4 Wind loading on cladding	Deflection	Intermittent	Lightweight cladding, including fixed and opening glazing; sheet siding	Extent of deflection depends on exposure for a given stiffness. Deflection is commonly designed not to exceed 1/240 of the span in order to avoid damage to sealants or glazing
5 Chemical changes:				
a) Corrosion	Expansion	Continuous	Iron and other ferrous metals	Depends on protection or on corrosion resistance of material; electrolytic corrosion may require consideration. Corroding fixings can seriously disrupt cladding
b) Sulphate attack	Expansion	Continuous	Portland cement based products in construction where soluble sulphate salts (e.g. from high-sulphate bricks) and persistent dampness present	Significant for cladding where the construction affected has cladding such as mosaic or other tiling or rendering, bonded directly to it
c) Carbonation	Contraction	Continuous	Porous Portland cement products, such as concrete, lightweight concrete, asbestos-cement	Not very significant unless distortion might result—for example, asbestos cement sheets painted on one face only
6 Vibration (from traffic, machinery, wind forces)	Generation of noise, possible loosening of fixings, disturbance of glazing seals	—	Lightweight cladding, sheet siding	Noise discomfort to occupants; possible rain penetration past seals by "pumping" action of glazing or spandrel panels. Natural frequency of cladding or panels may influence response
7 Physical changes:				
a) Loss of volatiles	Contraction, loss of plasticity	Short or long term depending on materials, exposure	Some sealants, some plastics	Contributes to age-hardening of some sealants. May lead to embrittlement and distortion of some plastics
b) Ice or crystalline salt formation	Expansion and possibly disruption in some building materials	Dependent on weather conditions	Porous natural stones, very exposed brickwork	Damage usually confined to spalling and erosion of surfaces

apply to sealant-filled joints. Here, however, an additional step is necessary to take account of the sealant's "movement accommodation factor" (MAF). MAF is expressed as a percentage, which should not be exceeded for that material, thus:

$$\text{MAF} = \frac{\text{Movement}}{\text{min. joint width}} \times 100$$

For design the expression can be rearranged thus:

$$\text{min. joint width} = \frac{\text{movement} \times 100}{\text{MAF}}$$

If the total range of expected movement at a joint is 2 mm, say, and a potentially suitable sealant has a MAF of 25%, then:

$$\text{min. joint width} = \frac{2 \times 100}{25}$$

and minimum permissible joint width is therefore 8 mm. Note that this would then be the smallest joint width permissible at *any time in service.* Clearly, if a joint, at the time of erection on, say, a cold day had a width of 8 mm, then the width on a subsequent hot day would be less than the permitted minimum of 8 mm. To safeguard against this possibility, since the conditions that will prevail at the time of construction are not known in advance, the total range of expected movement can be added to the calculated minimum (in the example 8+2=10 mm) as an adjusted minimum width permissible at the time of assembly. (A different MAF value is provided depending whether the material is used in compression/tension or in shear, but the calculation required is the same in each case). If the minimum width required for installation is larger than the minimum calculated, then that larger width must be adopted as the limit value. The upper permissible working limit of joint width may then be established, for sealant filled joints, by the width beyond which there is a risk that the material will slump or by the cost of the repetitive applications of sealant that may be necessary in very wide joints.

Digest 199 and the BRE Graphical Aids handbook [1] indicate how the working limits of width established for a joint can be compared with inaccuracies and movements in service so as to determine the optimum sizes for components and construction and obtain the best probability of satisfactory assembly and performance in service.

Inaccuracies and movements influence both the performance of joints and the durability of jointing materials and many joint failures would have been avoided if more careful consideration had been given to these influences. However, failures due to degradation of jointing materials cannot be wholly avoided if their durability is less than that of the cladding, as is usually the case. Building owners know that paintwork will need to be renewed, and the probable frequency with which the need will arise. In the case of jointing materials, though, the building owner is often not aware of the need to renew and cannot know the jointing materials on which design, in respect of inaccuracies and movements, was based, unless he receives guidance from the designer.

Inaccuracies and movements at fixings

The design of fixings to resist loads is not dealt with here; the aim of this digest is to draw attention to factors that may negate an otherwise satisfactory design. These factors include movements and inaccuracies in terms of their effects both on the fixings themselves and on the cladding.

Fixings between cladding and structure are of two main types, supporting or restraining, though both types also position the cladding units in relation to each other and to the structure. For present purposes the important feature of the "supporting type" is that, where it provides a rigid connection between cladding and structure, it provides a datum from which relative movements in both will operate (as at the base of Fig. 1). It is essential therefore to assess the amount of relative movement that will accrue as a result elsewhere (for example, at restraining fixings, at joints, at the underside of the next bearing above) and make corresponding provision. Provision for movement at fixings introduces a potential conflict of design requirements for accommodation of relative movement and for mechanical soundness and rigidity. The design problem is further complicated by the need to make separate provision for inaccuracies.

Solutions to the problem depend on the form of the cladding. Some solutions may be primarily intended to provide adjustability though permitting some movement (as in Fig. 2a); others may take more deliberate account of relative movement (as in Fig. 2b) but place appreciable demands on accuracy. Codes of Practice such as CP 297 and CP 298 provide useful guidance on differential movements, but both Codes consider that "accuracy in the construction of of the background structure is essential, otherwise the fixings . . . will not fit". Unfortunately, the parts of the structure most concerned are usually those least amenable to the achievement of accuracy, and adjustabilities in fixings commonly prove inadequate.

As explained in Digest 199, inaccuracies follow probability distributions. There is never certainty that inaccuracies will lie within required limits without correction, only an increasing probability that they will do so as the required limits are increasingly widely spaced. Conversely, if the limits are close, for example because the adjustability range of a fixing is small, there is increased probability that inaccuracies will exceed the limits.

Some commonly used cladding fixings have adjustability ranges that set very close limits. The practical significance is not merely the increased probability that inaccuracies will exceed the adjustability but that, very often, it is practicable neither to rectify the inaccuracies nor to devise on site an entirely satisfactory way to accommodate them. For these reasons also, even the best supervision on site does not necessarily solve the problem. A BRS survey of curtain walling [2] in the 1960s suggested that adjustment horizontally at right angles to the cladding needed to cover a range of 75 mm. This large value

reflects the difficulty of controlling the plan shape of the structure at any one floor level, coupled with the need to take account of relative misalignment between all successive floors. For the latter reason the survey report also suggested a design separation distance of 50 mm between curtain wall cladding and structure. Experience and the measured data in BS 5606 suggest that in most circumstances, whatever the form of the cladding, adjustabilities smaller than ± 25 mm, in any of the three major axes, are likely to carry appreciable risk of unsatisfactory fit. Some pitfalls in the design and construction of adjustable fixings are illustrated in BRE Current Paper CP 28/77 [3].

Inaccuracies have an indirect but important influence on the durability of fixings. Inadequate design consideration of inaccuracies often leads to the adoption of poor site practices intended to overcome the resultant problems of fit at fixing positions and bearings. When it is unnecessary to devise ad hoc solutions as construction proceeds it is much more likely that mechanically secure and durable fixings can be achieved. There remains the potential problem that fixings, upon which the security of the cladding depends, may be permanently concealed from view in environments that may encourage corrosion, and subjected to loads and movements that may disturb them. Designers should consider the need to provide access for periodic inspection during the life of the building; such access also makes possible the future replacement of cladding components.

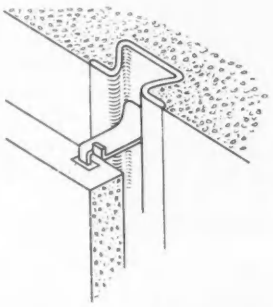

Fig 2(a) "Some . . . provide adjustability though permitting some movement"

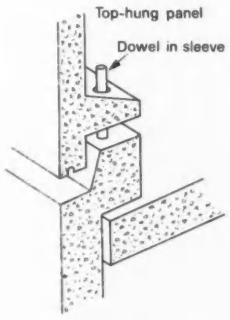

Fig 2(b) ". . . others may take more deliberate account of relative movement"

Distribution of movements by fixings

The character of fixings is illustrated in principle in Fig. 3, and the corresponding design implications can be summarised as:

Supporting type A: if the fixing provides a rigid connection between cladding and structure then its effects in distributing relative movements elsewhere need to be assessed.

Supporting type B: need to provide for relative movements in the direction "X".

Restraining type C: need to provide for relative movements in the direction "Y".

Restraining type D: need to provide for relative movements in directions "X" and "Y".

All types: need to provide for inaccuracies in each of the three major axes, noting that inaccuracies in the axis horizontally at right angles to the cladding plane may be large and require both large adjustability and a separation distance.

Practice commonly departs from these principles and often no problems arise because, for example, sizes are small or stresses are not damaging or rigid fixings "give" a little. However, the diagram indicates the factors that need to be assessed so that there is no departure from principles without prior consideration of the consequences in a specific application. Where cladding is supported directly by the structure, rather than indirectly via supporting fixings, there is a similar need to consider the effects of the supporting bearing on the distribution of relative movements. As

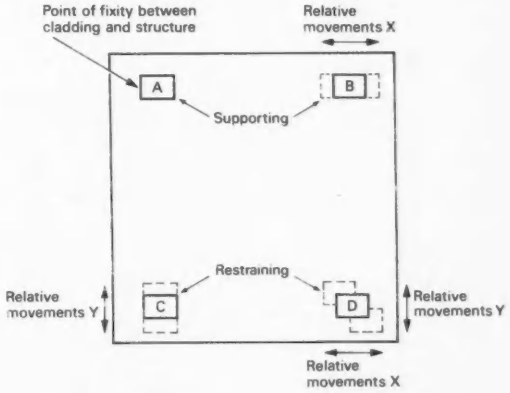

Fig 3 A top-hung cladding unit (in elevation) illustrates in principle how the distribution of relative movements can be determined from examination of the arrangement of fixings. In this example, fixing A is a type that permits no relative movement.

with designs in which more than one fixing provides a rigid connection between a cladding unit and the structure, the distribution will be influenced by the frictional restraints offered by fixings and bearings. In Fig. 4, for example, each cladding unit is supported by two fixings, either of which might offer the greater restraint to relative movements in service. In this case it is safer to assume that the movements in any two adjoining units will be concentrated at the joint between them, rather than that they will be shared equally by all joints. Alternatively, fixings may be so designed that, as in Fig. 3, the distribution of relative movements conforms to a predictable pattern.

Finally, in this section, consideration is given to fixing by adhesion, such as the bond between rendering and background, rather than by mechanical means. Relative movements are then important in that they can be accommodated only by stress in the materials and at interfaces.

In traditional uses of renderings the need to provide "soft" joints at intervals did not arise. However, in more recent uses of rendering, often as a base for mosaic or other tiling, new factors are present. These are the use of renderings on structural in-situ concrete, the greater heights of buildings, and the use of uninterrupted renderings across the changing backgrounds provided by composite construction. As a result of the first of these factors, relative movements arise from initial and long-term shrinkage in the in-situ concrete and from compression and creep under load.

The problems are accentuated by the second factor, the greater sizes producing greater total relative movement between structure and rendering. The third factor, changing backgrounds, introduces the possibility that different parts of the background are differently loaded or behave differently under similar loadings. At the same time, the differing backgrounds may respond differently to changes in ambient conditions and provide differing bond strengths at their interface with the rendering. All of these circumstances introduce the need for "soft" joints at intervals in tiled or rendered and tiled finishes. It is normally sufficient to provide horizontal soft joints in these finishes at storey height intervals and vertical or horizontal soft joints to coincide with joints, or changes in materials or form, in the background.

Desirable features of cladding fixings

There is, of course, no optimum design of fixing with universal application. However, in the following list each feature might be considered in turn for its relevance to a particular design context:

provide, where appropriate, a "designed clearance" between cladding and structure;

separate "provision for adjustment" from "provision for movement";

provide for movement, where necessary, following explicit consideration of amounts and directions, and of the effects of inaccuracies or provisions made for movement;

ensure that adjustability is not constrained by other parts;

avoid methods for providing adjustability that cannot be dissociated from strength (eg varying depth of engagement of a bolt in a socket);

provide largest practicable adjustability in each of the three major axes;

avoid a multiplicity of parts, particularly if they might be wrongly interchanged;

provide adjustments that can be readily made on site (a good solution, where practicable, is to design so that fixing devices can be plumbed and aligned as a separate operation before attachment of cladding);

provide adjustments that can be readily locked in their final positions to produce a secure fixing;

avoid different bolt sizes that require different torques;

design so that it will be apparent on visual inspection whether or not a fixing has been made as intended;

design for periodic inspection during building life.

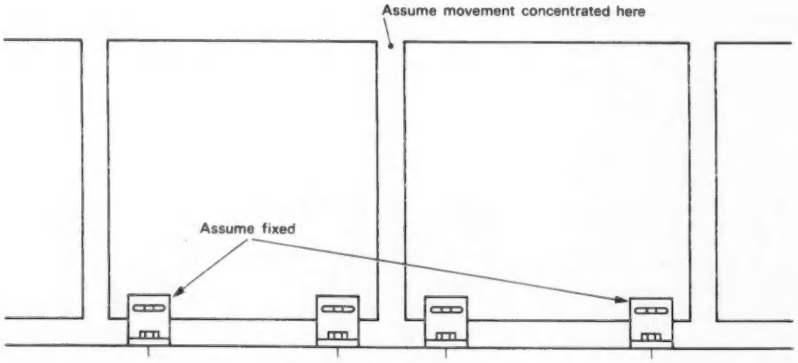

Fig 4 "... safer to assume that the movements in any two adjoining units will be concentrated at the joint between them..."

References and further reading

1 Graphical aids for tolerances and fits; HMSO, London; £15·50.
2 Adjustable fixings for curtain walling; BRE Current Paper Design Series 29.
3 Jointing specifications and achievement: a BRE survey; RB Bonshor; BRE Current Paper CP 28/77.

BRE Digests

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British Standards

CP 297:1972 Precast concrete cladding (non-loadbearing)
CP 298:1972 Natural stone cladding (non-loadbearing)
BS 5606:1978 Accuracy in building

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